1 Compute the Energy, and Time sums

$$
\begin{aligned}
E &= a_0 + \sum_i a_i s_i && (1)\\
(E{\cdot}t) &= b_0 + \sum_i b_i s_i && (2)\\
a_0 &= -p \sum_i a_i && (3)\\
b_0 &= -p \sum_i b_i && (4)
\end{aligned}
$$

$s_i, i = 1 \ldots 5$, are unsigned 12 bit ADC samples. p is the pedestal. a_i and b_i are signed 16 bit coefficients. a_0 and b_0 are signed 32 bit numbers. The results are signed 32 bit.

The coefficients are computed from optimal filtering energy weights A_i, and time weights B_i

$$
\begin{aligned}
a_i &= A_i \times 2^n && (5)\\
b_i &= B_i \times 2^{n+\mathcal{S}_t} && (6)\\
\mathcal{S}_t &= -17 && (7)
\end{aligned}
$$

n is chosen channel by channel, gain by gain, as the largest value that ensures $|a_i| < 2^{15}$, and $|b_i| < 2^{15}$. $\mathcal{S}_t$ is a fixed parameter of the algorithm. $\mathcal{S}_t = -17$ was chosen so that typically $|b_i| < 2^{14}$, and unusually high time weights will not downscale the energy coefficients. $\mathcal{S}_t$ also affects the time range that this implementation of the algorithm can measure. The time weights are assumed to be in units of 1 ps times the energy scale.

2 Divide by the Energy

The absolute value of the Energy $|E|$ is shifted left by $m + 2$ bits, until its leading (1) bit is lost in the 32 bit representation. m is the number of redundant sign bits in $|E|$. 12 MSB of the shifted value are used to lookup the inverse of the Energy D_i in a table. The table is initialized with

$$
\begin{aligned}
D_i &= \frac{2^{28}}{i + 2^{12}} \qquad (i > 0) && (8)\\
D_0 &= 2^{16} - 1 && (9)
\end{aligned}
$$

The time sum $(E{\cdot}t)$ is shifed by the same amount $m+2$ as $|E|$ was shifted, and the 16 MSB are multipied by D_i. The result is

$$t = 2^{32} \times \frac{(E{\cdot}t)}{|E|} \tag{10}$$

3 Floating Point Conversion

The Energy is converted to 32 bit floating point. The mantissa was allready prepared for the $(E{\cdot}t)$ time division lookup, and the exponent is computed as

$$\begin{aligned} \text{exponent} &= \mathcal{S}_E - n - m && (11) \\ \mathcal{S}_E &= 157 && (12) \end{aligned}$$

m is the number of redundant bits in $|E|$. $\mathcal{S}_E - n$ is a 16 bit constant coming with the energy coefficients for each channel and gain. The chosen value of $\mathcal{S}_E = 157$ reproduces the scale of the Energy weights, per ADC count.

4 Pulse Quality Factor χ^2

The pulse quality factor is computed as the quantity

$$\chi^2 = \sum_i (s_i - p - EH_i)^2 \tag{13}$$

where H_i represent the nominal pulse shape. The computation uses the formula

$$\chi^2 = \sum_i s_i^2 - 2p\sum_i s_i + p^2 + \frac{E}{2^{14}} \cdot \frac{\frac{E}{2^{14}} \cdot \frac{\sum h_i^2}{2^{12}} + 2p\sum h_i - 2\sum h_i s_i}{2^{12}} \tag{14}$$

where the pulse shape is scaled to satisfy

$$\sum_i a_i h_i = 2^{26} \tag{15}$$

The pulse shape coefficients $-2h_i$ are 16 bit quantities, but the scaling leaves only 12 bit precision. The energy multipications are performed with bits 14 to 29 of the energy sum result. $2p\sum h_i$ and p^2 are 32 bit constants, $\sum h_i^2/2^{12}$ is stored in 16 bits.

5 Constants Table Format

The calibration constants are stored in a table with 16 words for each gain channel. The first two sets are for the low gain of the first channel pair, followed by medium and high gain. Then follow the second pair of channels and so on.

ch 0, low
ch 32, low
ch 0, medium
ch 32, medium
ch 0, high
ch 32, high
ch 1, low
ch 33, low
ch 1, medium
...
ch 63, medium
ch 31, high
ch 63, high

The 16 words contain:

	high	low
0:	unused	
1:	unused	
2:	unused	
3:	a_1	b_1
4:	a_2	b_2
5:	a_3	b_3
6:	a_4	b_4
7:	a_5	b_5
8:	h_1	h_2
9:	h_3	h_4
10:	h_5	$-2p$
11:	$\sum h_i^2$	$\mathcal{S}_E - n$
12:	$-p\sum a_i$	
13:	$-p\sum b_i$	
14:	$2p\sum h_i$	
15:	$5p^2$	

6 Input Data Format

The input data is stored in 32 bit words. The lower (upper) half of the words contain data from the first (second) set of 32 channels. Each block of ADC data for 16 channels is preceded by one word storing gain select bits. The 5 samples for each pair of channels are stored together, followed by the next pair of channels, up to the 7th channel of the block. ADC data words are padded with zeros on the left to form unsigned 16 bit words.

<table>
<tr><td>g_{39}</td><td>g_{38}</td><td>g_{37}</td><td>g_{36}</td><td>g_{35}</td><td>g_{34}</td><td>g_{33}</td><td>g_{32}</td><td>g_{7}</td><td>g_{6}</td><td>g_{5}</td><td>g_{4}</td><td>g_{3}</td><td>g_{2}</td><td>g_{1}</td><td>g_{0}</td></tr>
<tr><td colspan="8">channel 32, sample 1</td><td colspan="8">channel 0, sample 1</td></tr>
<tr><td colspan="8">sample 2</td><td colspan="8">sample 2</td></tr>
<tr><td colspan="8">sample 3</td><td colspan="8">sample 3</td></tr>
<tr><td colspan="8">sample 4</td><td colspan="8">sample 4</td></tr>
<tr><td colspan="8">sample 5</td><td colspan="8">sample 5</td></tr>
<tr><td colspan="8">channel 33, sample 0
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channel 39, sample 4</td><td colspan="8">channel 1, sample 0
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channel 7, sample 4</td></tr>
<tr><td colspan="8">sample 5</td><td colspan="8">sample 5</td></tr>
<tr><td>g_{47}</td><td>g_{46}</td><td>g_{45}</td><td>g_{44}</td><td>g_{43}</td><td>g_{42}</td><td>g_{41}</td><td>g_{40}</td><td>g_{15}</td><td>g_{14}</td><td>g_{13}</td><td>g_{12}</td><td>g_{11}</td><td>g_{10}</td><td>g_{9}</td><td>g_{8}</td></tr>
<tr><td colspan="8">channel 40, sample 0
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channel 63, sample 5</td><td colspan="8">channel 8, sample 0
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channel 31, sample 5</td></tr>
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